DESCRIPTION OF THE DE SMET QUADRANGLE.

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GEOGRAPHY.

GENERAL RELATIONS.

Eastern South Dakota forms part of the Great Plains, lying in the broad, indefinite zone in which these plains merge into the prairies of the Mississippi Valley. It is comprised within the area of glaciation, and most of its surface features show the characteristics of a drift-covered region. The country is not level, but presents long, rolling slopes rising 300 to 800 feet above the broad valleys. The principal elements of relief are massive ridges, or mesas, due to pre-Glacial erosion, which are often crowned or skirted by long ranges of low hills due to morainal accumulations left by the ice along lines marking pauses of glacial advance and retreat. Further diversity of topography has been produced by the excavation of the valleys, especially that of the Missouri, which has cut a trench several hundred feet deep, mostly with steeply sloping sides. Between the moraines there are rolling plains of till and very level plains due to the filling of glacial lakes. The upper James River Valley presents a notable example of this lake-bed topography.

LOCATION.

The De Smet quadrangle is located between longitudes 97° 30′ and 98° west and latitudes 44° and 44° 30′ north. It is mainly in Kingsbury and Miner counties, but comprises portions of Beadle and Sanborn counties. It has an average width of a little more than 24½ miles and a length of about 35 miles, and its area is about 857 square miles. It lies on the east slope of James River Valley, and extends from the bottom of the valley up onto the eastern coteau.

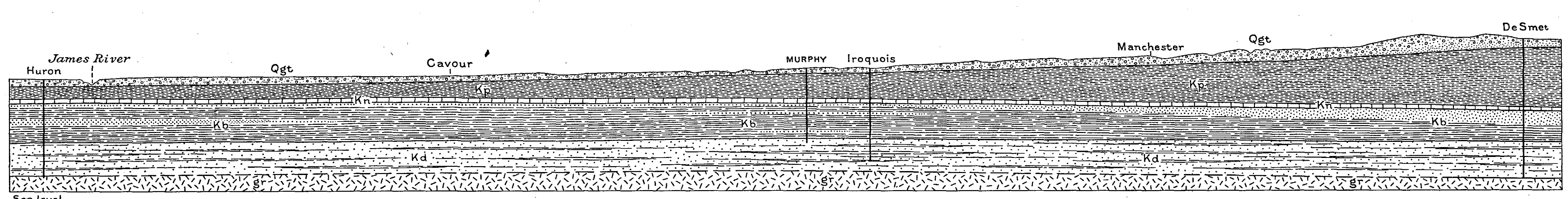

FIG. 1.—Sketch section from Huron to De Smet, showing the artesian wells extending to the Dakota water-bearing sandstone.

Qgt, Glacial till; Kp, Pierre shale; Kn, Niobrara formation; Kb, Benton formation; Kd, Dakota formation; gr, granite, including probably overlying Sioux quartzite in places.

Horizontal scale: 1 inch = 3 miles. Vertical scale: 1 inch = 1500 feet.

TOPOGRAPHY.

The region is in general flat, and its features are, with few exceptions, those of very subdued glacial topography, the basins being shallow and widely separated, and the swells very low. Rougher areas occur in the morainic regions, which are shown on the areal geology map. At some points the swells rise into hills from 15 to 25 feet high, which are more fully described under the heading "Moraines."

The surface of the quadrangle varies in altitude from 1850 feet above the sea on a narrow ridge on the middle of the east line of sec. 12, T. 111 N., R. 57 W., to about 1250 feet in the southwest corner near the middle of the north line of sec. 5, T. 107 N., R. 60 W. The generally smooth surface gives place to rougher land west of De Smet in a northwest-southeast strip 2 or 3 miles wide, and in the vicinity of the larger ravines on the west slope of the strip above mentioned.

DRAINAGE.

The general drainage is simple. The streams for the most part belong to the James River system. In the northeast corner of the quadrangle is an area, including about 40 square miles, which drains into the basin of the Big Sioux, or rather into a local system of lakes which sometimes overflow into it. In the southeast corner is a narrower area of about the same extent which drains into the Vermilion. The streams of the quadrangle are not simple consequent streams, but show the disturbing effects of the Pleistocene ice sheet. As would be expected from the relations of the quadrangle to the James River Valley and from the position of the higher and lower points, the general drainage is toward the southwest except in the two areas above mentioned and in the basins of some streams a portion of whose courses in another direction was early determined by the ice sheet.

The watercourses are not large and none carry running water throughout the year. Few of them even have water holes in the dry season. None of them have cut trenches over 15 or 20 feet in depth, or have flood plains of any importance. James River does not enter the area. The broadest watercourse skirts the east side of the rough area west of De Smet. This valley is 2 or 3 miles wide and contains two or three large lakes. The longest watercourse is Redstone Creek, which rises near the middle of the north boundary, near Bancroft, flows south to the vicinity of Carthage, turns southwest, and, reaching the bottom of the James River Valley, turns north, and then west, leaving the quadrangle near Alwilda, in Oneida Township. Branches of Redstone Creek and several other streams have similar courses curving roughly toward the southwest.

GENERAL GEOLOGY.

The surface of eastern South Dakota is in large part covered with a mantle of glacial deposits, consisting of gravel, sand, silt, and clay, of varying thickness, which are described in detail later, under the heading "Pleistocene deposits."

The formations underlying eastern South Dakota are seldom exposed east of Missouri River, though they outcrop in some of the hills where the drift is thin and in the banks of a few of the streams. The numerous deep wells throughout the region have, however, furnished much information as to the underground structure. There are extensive sheets of clays and sandstones of Cretaceous age lying on an irregular floor of granite and quartzite of Archean and Algonkian age. Under most of the region this floor of "bed rock" is over a thousand feet below the surface, but to the east it rises gradually to the surface. There is also an underground quartzite ridge of considerable prominence that extends southwestward from outcrops in southwestern Minnesota to the vicinity of Mitchell, S. Dak.

The lowest sedimentary formation above the quartzite is a succession of sandstones and shales of wide extent, termed the Dakota formation, which furnishes large volumes of water for thousands of wells. It reaches a thickness of 300 feet or more in portions of the region, but thins out and does not continue over the underground ridge above referred to. It is overlain by several hundred feet of Benton shales, with thin sandstone and limestone layers, and a widely extended sheet of Niobrara formation, consisting largely of chalkstone to the south and merging into calcareous clays to the north. Where these formations appear at the surface they rise in an anticlinal arch of considerable prominence along the underground ridge of quartzite, but they dip away to the north and west and lie several hundred feet deep in the north-central portion of the State. In the Missouri Valley they rise gradually to the southeast and reach the surface in succession, the Dakota sandstone finally outcropping in the vicinity of Sioux City, Iowa, and southward. The Pierre shale extends in a thick mantle into eastern South Dakota, lying under the drift in the greater portion of the region, except in the vicinity of the higher portions of the anticlinal uplift above referred to. It was, no doubt, once continuous over the entire area, but was extensively removed by erosion prior to the Glacial epoch. Doubtless the Fox Hills and Laramie formations once extended east of Missouri River, but they also have undergone widespread erosion and few traces of them now remain in the extreme northern portion of the State. Tertiary deposits appear to have been laid down over part of the region, as is shown by small patches still remaining in the Bijou Hills and other higher ridges.

The De Smet quadrangle is covered with glacial drift, with the exception of small alluvial flats along the streams. The underlying stratified rocks are not exposed, but data concerning them have been obtained from numerous borings made in sinking artesian wells. These rocks have a nearly horizontal attitude, as may be seen in fig. 1, and include representatives of the Cretaceous system and probably the Algonkian. Because of the relation of these underlying rocks to the water supply of the area, they will be briefly considered here.

ARCHEAN—ALGONKIAN ROCKS.

The old crystalline rocks, popularly called the "bed rock," underlie the Cretaceous throughout the whole quadrangle, and, judging from their altitude in adjacent areas, they are probably 1150 feet above sea at the southeast corner of the quadrangle, or 400 feet below the surface. From this point the surface of the rocks declines gently to the northwest toward a shallow east-west depression which extends from south of Iroquois to De Smet and which has an altitude of less than 200 feet above sea. The principal rock probably is a light-colored granite of supposed Archean age, which in places is overlain by red Sioux quartzite of Algonkian age. Dikes of eruptive rocks such as diabase may sometimes occur, though no distinct occurrences of any of these have been reported. The only borings in this quadrangle in which crystalline rocks are supposed to have been struck are at Vilas and Howard, where "granite" has been reported. The granite, judging from samples from the Budlong and Motley well, northeast of Hitchcock, and from some wells 5 or 6 miles north of Farmer, in Hanson County, is a fine-grained, light-gray rock, abounding in a transparent feldspar.

CRETACEOUS SYSTEM.

Of the subaqueous rocks, only the upper Cretaceous is known to occur in the De Smet quadrangle, but it is possible that there are also present the equivalents of the Lakota sandstone and underlying shales of the Black Hills region, which are of lower Cretaceous age. The Jurassic is almost certainly absent, for its area of deposition was far to the west. The Dakota, Benton, Niobrara, and Pierre have all been recognized in drilling.

DAKOTA FORMATION.

The Dakota formation is the principal water-yielding horizon of the region and supplies the more important artesian wells of North Dakota and South Dakota. In this quadrangle it nowhere comes to the surface, though it has been encountered in a number of the deeper wells.

The formation as exhibited in the rim of the Black Hills is usually a brown sandstone, hard and massive below, but thinner bedded above, having an average thickness of 100 feet. It varies from fine to coarse grained and usually is only moderately compact. In eastern South Dakota the formation lies on the Sioux quartzite, but in the vicinity of Mitchell it abuts against the higher portions of a quartzite ridge on which the Benton shales and sandstones overlap. The Dakota terminates at this overlap in an old shore line, which has considerable irregularity in outline and altitude, the latter due to local variations in amount of uplift. From this old shore line along the quartzite ridge the Dakota sandstone slopes toward the north, west, and south. It is believed that this shore line is nearly intact, for probably there was but little erosion before the deposition of the Benton. The dip of the sandstone is more rapid near the quartzite ridge, and gradually diminishes away from this ridge until the rock lies nearly horizontal. In this quadrangle the Dakota formation is a series of sandstones and shales mantling the crystalline rock surface already discussed.

The shale beds associated with the sandstone resemble those of the overlying formations, and, like them, contain calcareous concretions which may be mistaken for limestone strata. Sometimes, also, there occur concretions of pyrites large enough to hinder the drilling. The different layers of sandstone are often harder near the top, and this has given rise to the expression "cap rock." Frequently the drill has to penetrate several feet of hard rock before it reaches the water-bearing strata.

The Dakota sandstone is variable in thickness, but, as few borings have gone to its bottom, precise figures are available only for some limited areas. In the De Smet boring it appears to have a thickness of 425 feet, but it is probably thinner to the west. It appears to thin considerably toward the northwest corner of the quadrangle, and doubtless also to the southeast, as it overlaps the slope of underlying rocks. The Dakota is very nearly horizontal under most of the area, but rises gradually on the slope of the underlying crystalline rock ridge in the southeast corner of the quadrangle.

The well sections (figs. 2 to 6) on the next page exhibit the character and thickness of the formation in detail, and in the discussion of the sources of artesian water further light will be given on the number, thickness, and subdivisions of the sand strata in this formation.

In studying the sections it should be remembered that the data given by well borers, upon which a section is based, are indefinite in many respects. The drill commonly used is a hydraulic machine, in which a jet of water is used to bring up the borings; hence the exact character of any particular portion can not be very definitely learned, as the rock brought to the surface is usually pulverized and is mixed with mud from several strata. Moreover, unfortunately, the driller is usually not disposed to examine the deposit with much care, nor to measure carefully the exact position and thickness of many strata which would be of special interest to a geologist. The driller is interested chiefly in the water-bearing strata, and in only such of them as produce a flow sufficient for his purpose. When asked for a record of a particular well, he is apt to remember only the depths at which water was struck and at which the greatest resistance was encountered. It may, therefore, safely be concluded that the deeper sandstones are often thicker than is represented in the sections.

The Dakota formation is considered by some geologists to be a fresh-water deposit, as the molluscan fossils which are occasionally found in it are

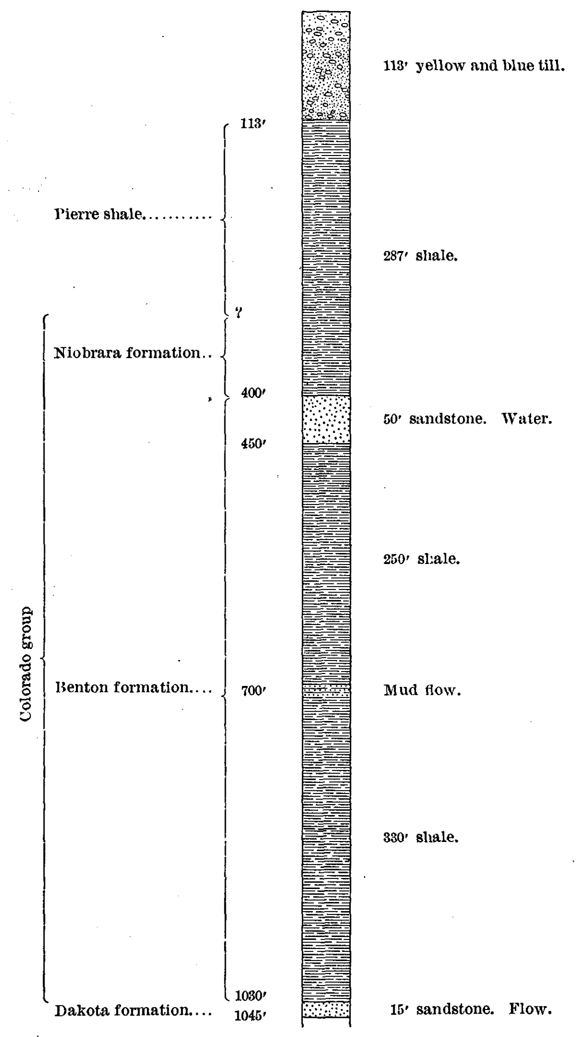

Fig. 2.—Section of Brooks well, NE. ¼ sec. 21, T. 112 N., R. 58 W.

of a few distinctly fresh-water species. Material from wells has afforded but little evidence as to organic remains in the Dakota sandstone. About Esmond shells of *Goniobasis*, a fresh-water form which occurs in Dakota sandstone in Nebraska and elsewhere, were obtained in quantity. They were found at a depth of 785 feet. Fossil leaves were found in a well near Hitchcock.

COLORADO GROUP.

The Colorado group includes two distinct formations. The first or lower is called the Benton

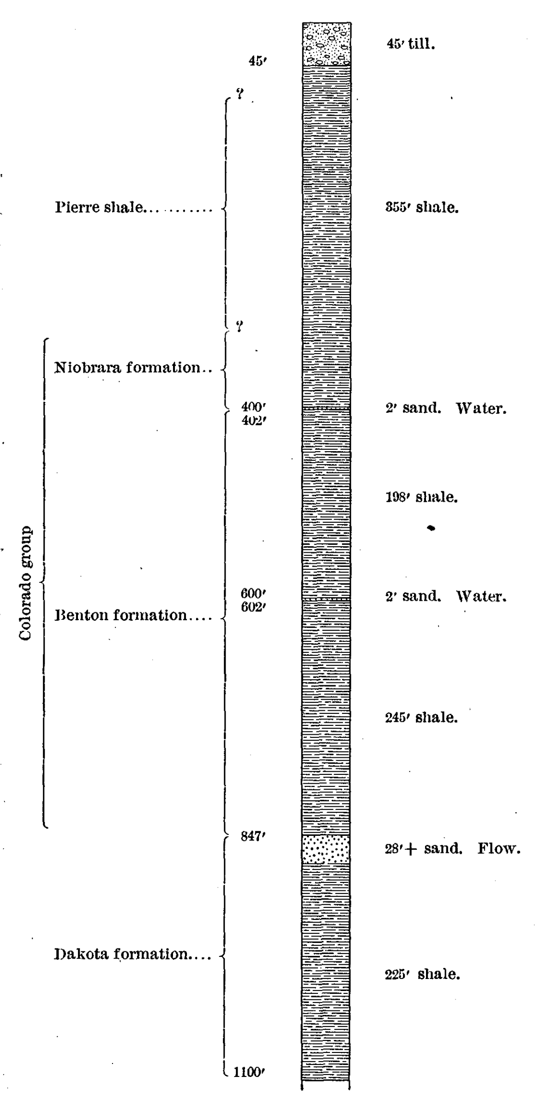

Fig. 3.—Section of well at Iroquois.

shale, so named because of its prominent development near Fort Benton, on the upper Missouri. In the southeast corner of South Dakota it consists of lead-colored or dark-gray shale containing calcareous and ferruginous concretions. Where it is exposed along Missouri River it is estimated to have a thickness of about 300 feet, but it thins eastward. In the vicinity of the Black Hills the Benton is much thicker, and is divided into several formations. There it consists largely of dark shale, but exhibits also layers of sandstone, sometimes of considerable thickness, and also a persistent layer of shaly limestone abounding in *Inoceramus labiatus*. These features are also traceable in southeastern South Dakota.

The second or upper member of the Colorado group is the Niobrara chalkstone, named from its prominence near the mouth of Niobrara River. It is usually of a drab color except where it has been weathered. It may be snow-white, but is more commonly of a light-straw color. It varies considerably in composition, often carrying a large proportion of clay. Owing to its variable composition it is not always clearly distinguishable from the Benton shale below. The purer chalk seems to be limited to lenses of large extent, merging into clay. In some exposures chalk may be found at one point and a few rods away its place may be taken by gray clay.

Benton formation.—In this quadrangle the Benton includes a relatively larger amount of sandstone than in most other places. It is not exposed at any point in this quadrangle, but the data derived from wells indicate that it is composed of the following strata: Beginning at the top there is immediately below the chalkstone a stratum of plastic clay or shale. This seems to be extremely variable in thickness, ranging from 1 to 50 feet. Beneath this clay is a layer of rusty sandstone which is exposed farther south and which varies

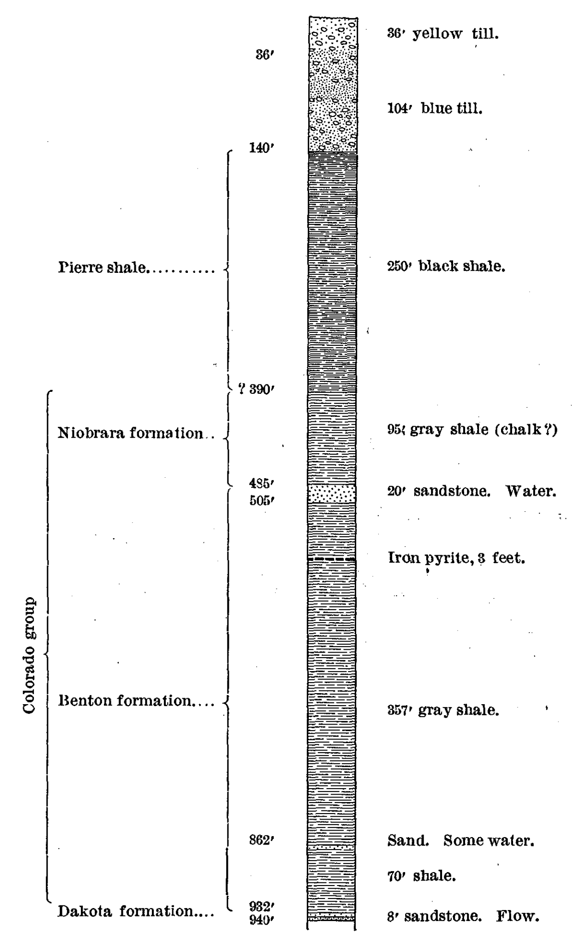

Fig. 4.—Section of Spear well, NE. ¼ sec. 19, T. 110 N., R. 57 W.

from 10 to 100 feet in thickness. Below the sandstone is a thick layer of shale in which, near the middle, there seems to be a thin stratum of sand sufficiently continuous to carry water, which flows when tapped by wells. The whole formation has a thickness of 450 to 500 feet, as nearly as can be judged from well records.

Owing to the failure of drillers to recognize the chalk rock to the north, it is difficult to ascertain the upper limit of the formation. Apparently the first sandstone reported is the upper sandstone of this formation, and on this assumption the Benton beds comprise the strata from 400 to 847 feet in the Iroquois well (fig. 3); from 485 to 932 feet in the Spear well (fig. 4); from 365 to 837 feet in the Murphy well; from 400 to 1030 feet in the Brooks well (fig. 2); from 440 to 886 feet in the Everest well, and from 840 to 1185 feet in the De Smet boring (fig. 5), the latter indicating thinning eastward.

The sandstone contains sharks' teeth and traces of vegetation where it outcrops, and a stratum of fossiliferous limestone 580 feet below the surface in the vicinity of Woonsocket. Some of the limestone fragments were submitted for examination to Dr. T. W. Stanton, who reports that at least three species are represented, one of which is a small *Nucula* with striated surface, that may be the young of *N. cancellata* M. and H.; another is possibly a young *Mactra;* and the third, the most common form, is probably a *Lucina*. The specimens were too imperfect to permit more definite determination. They were found 250 feet below the chalkstone and about 100 feet above the main water flow. These fossils are distinctly marine in character and indicate that this stratum is a part of the Benton. This fossiliferous horizon seems to have a considerable extent around Woonsocket. Other Benton fossils, including *Mactra* and *Fasciolaria* were found in the Ashmore well, near Artesian.

Niobrara formation.—The most characteristic feature of this formation is the chalkstone, but no doubt considerable deposits of clay should be con-

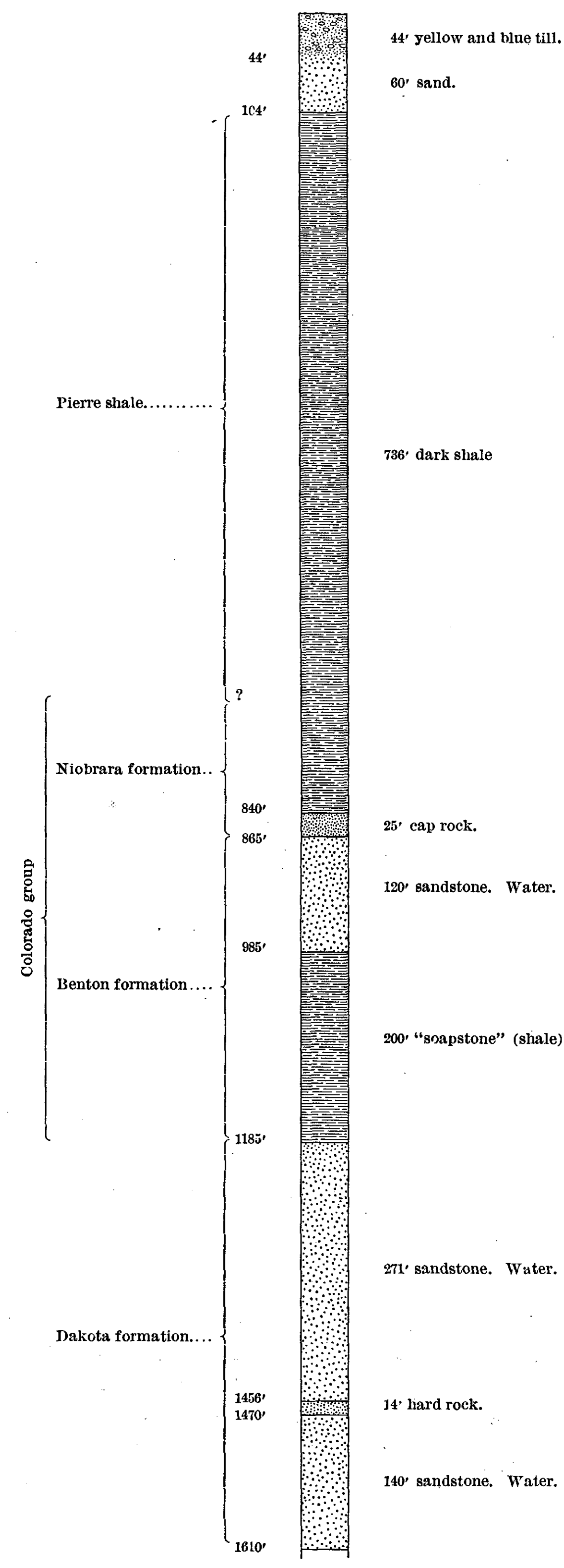

Fig. 5.—Section of well at De Smet.

sidered as included in it. As the formations both below and above are clay, the areal distribution of the Niobrara can not be very sharply defined in this drift-covered region. It is especially difficult to recognize the different beds in wells, for there the chalk has not been exposed to atmospheric action, and has a leaden color, closely resembling the gray clays of the Benton. Well drillers do not always recognize chalkstone, so that there is considerable uncertainty in the records of borings, a fact which

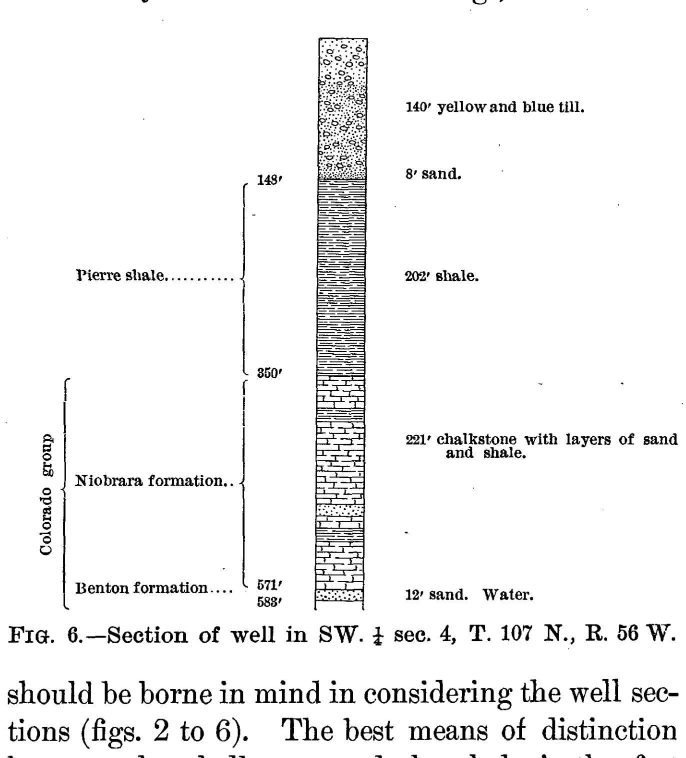

Fig. 6.—Section of well in SW. ¼ sec. 4, T. 107 N., R. 56 W.

should be borne in mind in considering the well sections (figs. 2 to 6). The best means of distinction between the chalkstone and the shale is the fact that when pulverized the chalkstone does not become plastic and sticky like the shale. The chalkstone behaves more like a sandstone, from which, however, it is readily distinguished by its softness and lack of grit. Features observed farther south in the James River Valley indicate that the chalkstone may have been formed in part contemporaneously with clay. Clay with a very little calcareous matter has been found within a few feet horizontally of typical chalkstone.

Well sections showing the character and relations of the Cretaceous formations in different portions of the quadrangle are given in figs. 2 to 6.

MONTANA GROUP.

The Montana group is elsewhere made up of two formations, the lower being the Pierre, so named because it constitutes the main part of the Missouri bluffs at Fort Pierre, and the upper the Fox Hills, so named from its occurrence in the hills of that name north of Big Cheyenne River. Only the lower portion of the Pierre is present in this quadrangle.

Pierre shale.—As developed here the Pierre shale consists almost entirely of dark plastic clays, sometimes hardened into shale, with occasional calcareous concretions, and perhaps some thin layers of sand or sandstone. This formation probably underlies the whole quadrangle immediately above the chalkstone. It is comparatively thin, however, particularly along the southern boundary, where it is not over 15 to 20 feet thick. As the lower formations dip toward the north, the Pierre becomes thicker in that direction, and has a maximum thickness of 150 to 200 feet along the northern boundary. Well drillers do not report sandstone in it, but as it contains a well-defined water horizon it seems probable that there is a thin sandy stratum, or possibly a bed of porous chalk, a little above its base. No fossils have been obtained from this formation in this quadrangle.

QUATERNARY SYSTEM.

PLEISTOCENE DEPOSITS.

The formations thus far described are sedimentary, and with the possible exception of the Dakota are of marine origin. To these the Pleistocene deposits present a marked contrast, not only in their origin but in their mode of occurrence. They are the products of glacial action and overlie all earlier formations without respect to altitude, forming a blanket over the whole quadrangle with the exception of a few square miles that are covered by alluvium. The deposits include till or bowlder clay, morainic material, and stratified or partly stratified clays, sands, and gravels formed along abandoned river channels and terraces. The bowlder clay forms a great sheet, spreading over nearly the whole quadrangle. The morainic material occurs in a series of rough, knobby hills and ridges that cross the quadrangle, as is shown on the areal geology map. The channel and terrace deposits are found in valleys and over flat areas, mainly near the morainic ridges.

It is not certain that there are in this quadrangle any post-Cretaceous beds of pre-Glacial age. Near the southwest corner there are certain water-bearing beds below the till which may be distinctly older. From wells in that area have been obtained pieces of peat and numerous fresh-water shells, which may come from a pre-Glacial marsh deposit that may have been connected with the flood plain of the pre-Glacial James River.

Till or bowlder clay.—The till presents here the features common to the deposit found elsewhere, as in central Minnesota, Iowa, and Illinois. It is an unstratified mixture of clay, sand, and worn pebbles and bowlders, the latter sometimes attaining a diameter of several feet. In it are local developments of stratified sand, sometimes mere pockets, sometimes portions of channels of considerable length, and sometimes sheets that locally separate the bowlder clay into two or more members. The till of this quadrangle is much more clayey than that found farther east, perhaps 90 per cent being clay. This is because of the long distance the ice moved over and deeply eroded the dark-colored clays of the Cretaceous. For the same reason the erratics are perhaps less frequently striated and planed.

The till here, as elsewhere, exhibits an upper, yellowish division, known as yellow clay, and a lower blue portion. The upper clay is simply the oxidized or weathered form of the lower, and the separation between the two is not very clearly defined. They are sometimes distinguished in sections, but not always. The blue clay is apt to be confused by well drillers with the underlying Cretaceous clay of similar color, so that in their reports part of the Cretaceous clay may be included in the Pleistocene formation.

No distinct traces have been found of a general subdivision of the till into different members, as in some other localities, and the whole is believed to have been formed by the Wisconsin ice sheet. It should be noted, however, that even if there be a division there is little likelihood that it would be reported by well borers, for the Pleistocene is not often the source of water supply, and hence the drillers are less critical in their observations of it than of the underlying rocks. Occasional fragments of wood have been reported from it, but in every case they proved to be isolated pieces and not parts of a "forest bed."

The surface of the till shows the characteristic irregularity common to it elsewhere. There are many small, irregularly placed hills or knolls and minor basins without outlet. These features are fainter than usual, and the general surface is much more nearly an even plain than is common in drift-covered regions. This is because the quadrangle lies to the north of the principal moraine. The pre-Glacial surface had been acted upon by the ice for a long period, and, as the underlying rocks were soft and somewhat uniform in character, it was planed down more evenly than usual. There has also been a considerable amount of filling of the minor basins with silt, laid down by waters escaping from the ice soon after deposition of the till, and also, in more recent times, with wash, resulting from rain and the melting of snow. In some localities considerable silt has been deposited by the wind. At most points, however, the surface is now nearly as it was left by the ice sheet.

The thickness of the till in this quadrangle is estimated to average considerably over 100 feet. In general under the eastern half it is over 100 feet, attaining 200 to 250 feet in the morainic area northwest of De Smet. Farther south it is less, though it does not fall below 125 feet. In the west half, while in general it is less than 100 feet, there are areas of some extent in T. 110 N., R. 59 W., and T. 111 N., R. 59 W., where the thickness is less than 50 feet.

Several causes tend to render the thickness of the till uncertain in some cases. In the first place, the thickness varies greatly in short distances. This may be due to the unevenness of the pre-Glacial surface. In the second place, as already stated, local beds of sand occur in the till as well as under it. These may be mistaken for one another and thus false estimates of the thickness be made. Finally, in some places, especially in the southern part of this quadrangle, in contact with the sand below the till and dipping from it at a small angle are Cretaceous sand strata which are difficult to distinguish from the sands of the drift. This difficulty is increased by the close resemblance of the Cretaceous clays to the till and by the fact that sometimes the two may not be separated by sand. For all these reasons the estimates given above need to be taken with some allowance.

Moraines.—The moraines of this quadrangle are shown on the areal geology map. With a few exceptions they are not a conspicuous feature. Generally they consist of a low, broad swell showing the usual surface of the till, except that occasional scattered peaks rise abruptly 15 to 25 feet above the adjoining surface. The swell may have an altitude of 20 or 30 feet above the till on either side, into which it insensibly merges. This merging is particularly well shown in the moraines in the lower part of the quadrangle. The high ridge west of De Smet rises somewhat abruptly and is three or four times the height of the other moraines.

The moraines are composed of material similar to that of the till, but the ridges are more stony. They contain numerous bowlders and considerable masses of gravel.

The moraines of this quadrangle include different members of two principal moraines, which are commonly known as the Gary and Antelope moraines.

The Gary or second moraine of the Wisconsin epoch is named from its prominence near Gary, S. Dak. It is conveniently divided into three or four members. The first enters the quadrangle from the north near the middle of T. 112 N., R. 57 W., and follows a nearly due south-southeast direction, leaving the quadrangle in the southern part of T. 109 N., R. 56 W. This moraine forms a ridge, developed on a grand scale, which begins on the western edge of the Coteau des Prairies, and from its higher points there is an extensive view across the James River Valley on the west, looking down a long slope into a basin 500 feet below. On the east the descent is abrupt for 100 to 150 feet, into a broad valley which runs southeast, parallel with the ridge. This part of the moraine corresponds to two members already mapped in the Olivet and Parker quadrangles. Another member, much less prominently developed, branches off west of De Smet from the one first described, and, leaving it at a small angle, passes nearly due south to the boundary of the quadrangle near Vilas. A third member branches off a little farther north, but is scarcely recognizable as distinct in the main part of the quadrangle and is but faintly developed until it reaches the vicinity of Artesian. The low swells and knolls which represent this member would scarcely be worthy of separate notice were it not for the prominent development of this moraine north of Letcher and west of Woonsocket, beyond the limits of this quadrangle.

The Antelope, or third moraine, named from a locality in western Minnesota, is also faintly developed except in its southern portion. As near as has been determined it is represented by several scattered knolls and ridges north and west of Iroquois, which continue southwest along both sides of Marsh Creek and connect with a belt of rough country in the Huron quadrangle.

Ancient channels and terraces.—Throughout the quadrangle are numerous abandoned channels and terraces, the locations of which are shown on the areal geology map. Usually, though not always, these are clearly separable from the present drainage lines, and are evidently much older. In some of the shallower channels the older deposits can not be clearly distinguished from those of recent origin, and the latter have been included under this head. The ancient channels correspond generally with the present waterways, which are the puny successors of the old streams, though in some cases the direction of drainage has been so changed that some of the present valleys are connected by a network of older channels.

These channels vary from shallow, flat-bottomed depressions, through which streams passed for a comparatively short time, to a trough 20 to 40 feet deep that contains an abundance of coarse material, showing that it was long occupied by a vigorous stream. The coarser deposits are usually largely covered with finer material. Where the channel deposit has been cut through by the deeper trenching of a later stream, similar differences in the character of the material also occur. In some cases the old channel deposit is at a height of 50 to 60 feet above the present stream. In many cases, however, the old deposits have been slightly trenched, as the later drainage has passed off in another direction.

The older channels connect with the terraces of the present streams, particularly along James River, where sometimes two are present. East of Huron the terraces are about 40 and 60 feet above the stream. They are not always distinctly marked, but may merge into one another. The usual sign of such a terrace is the sharp, stony edge capping the river bluff and the generally flat surface extending for many rods back from the stream.

These ancient channels carried off the water from the front of the ice sheet at its different stages. The arrangement of the channels is evidence of the former existence of an ice sheet over this region. The size, and particularly the course, of some of the channels and the amount of coarse material found in them can not well be explained by reference to any other agency.

The order in which these channels were occupied may be learned from the map, but it should be remembered that it is impossible to represent the order of their occupation with minute accuracy. The succession is, however, much simpler in this quadrangle than in the adjacent area. When the ice receded during the Wisconsin epoch the northeast corner of the quadrangle was first uncovered. Hence the broad channel crossing that area in a southeast direction was occupied by a stream draining the eastern side of the ice lobe for a long time before any other channel was developed. The next channel was that of the upper Vermilion. These two channels are to-day the only ones not belonging to the James River system. All succeeding channels, which have a prevalent south and southwest direction, lead to James River, and as the ice receded toward the northwest they were uncovered in regular order. Some of them drained the eastern side of the ice lobe for a considerable time. This was especially true of Redstone Creek. Other channels were probably occupied only during the time when the ice melted from over their valleys.

Ancient lake deposits.—In this region there are areas which may conveniently be called extinct lakes. This does not mean necessarily that they were ever wholly occupied at any one time by sheets of water. It is probable that as the ice receded toward the north the southern portion of these lakes in each case was first occupied by water and filled by the accumulating sediment from the streams draining the adjacent ice sheets, and that successive areas were filled in a similar way, until the region became a flat plain covered with sand or clay, with points of the underlying till rising above it like islands and with shallow channels winding about irregularly upon it. In some cases these plains seem to have been covered for a period by shallow bodies of water.

One of these areas, which has already been described in the Mitchell and Alexandria folios, enters the southwest corner of the De Smet quadrangle, where it occupies a small area in Union Township. It may have extended over a wider area than mapped, for the distinction between it and the surrounding level till is not marked.

RECENT DEPOSITS.

Since the retreat of the glaciers there has been very little deposition in this quadrangle. The present streams and the winds are, however, making some changes in the surface deposits. The gravels of the ancient channels and lake basins are thickly covered with fine silt, which is in part dust deposited from the air.

GEOLOGIC HISTORY.

The earliest phases of the history of the region of which this quadrangle is a part may be stated very briefly. The granite which is found in the deeper wells of this quadrangle, and which underlies much of the region, represents a stage preceding the deposition of the Sioux quartzite. It formed a land surface which occupied central Minnesota and from which was derived, both by the action of streams and by wave erosion along the shore, the material that now forms the Sioux quartzite. This formation, though widely present in the region, is not known to occur in this quadrangle. The deposits consisted mainly of stratified sands and were thicker toward the center of the broad area that now extends southwestward from the vicinity of Pipestone, Minn., and Sioux Falls, S. Dak. After their deposition there seems to have been an epoch of slight volcanic and igneous outflow, as is shown by the occurrence of basic material in a dike at the quarries at Sioux Falls and in borings at Yankton and Alexandria, S. Dak.

Through silicification the sandstone was changed to an intensely hard and vitreous quartzite, while some local clay beds were transformed to pipestone and more siliceous red slate, as at Palisade. Microscopic examination shows that this silicification was effected by the crystallization of quartz around the separate grains of sand until the intervening spaces have been entirely filled. The material of the quartzite was laid down in the sea, and at first may have included scores, or even hundreds, of feet of material above that which is now found. In time the region was lifted above the sea, and during some part or all of the long Paleozoic age it was a peninsula. It may at times have been submerged and have received other deposits, but they have been eroded. That it was not far from the ocean, at least during a portion of the time, is attested by the occurrence of Carboniferous rocks under Ponca, Nebr.; and since Paleozoic, Jurassic, and Triassic rocks are found in the Black Hills, it is evident that the shore line during those ages repeatedly crossed the State some distance to the west.

With the beginning of the Cretaceous period the sea began to advance over the land; in other words, this quartzite area began to subside relatively. As the waters gradually advanced, waves and currents carried away finer material and left well-washed sands spread as more or less regular sheets extending from the eastern shore line across the shallow sea to the Rocky Mountains. From time to time the activity of the erosion diminished and finer material, or mud, was deposited, or both the sands and the mud may have been laid down contemporaneously in different areas. It is not unlikely also that strong tidal currents, sweeping up and down the shallow sea, may have been important in distributing so uniformly the sands and clays. Where the currents were vigorous, sands mainly would be laid down; where they were absent or very gentle, clay would accumulate; and not improbably these tidal currents would shift from time to time by the variable warping of the sea bottom and the shore. At any rate, several continuous sheets of sand lie over this region and are more or less perfectly separated by intervening sheets of clay. The process resulted in the Dakota formation.

The fossils found in the Dakota formation are some fresh-water shells and leaves of deciduous trees, like the sassafras, the willow, the tulip tree, and the eucalyptus.

During Colorado and still later Cretaceous times marine conditions prevailed and the region was further submerged until the shore line was probably as far east as central Minnesota and Iowa. During most of this time only clay was deposited in this quadrangle, but calcareous deposits accumulated in the form of chalk during the Niobrara epoch, when the ocean currents brought less mud into the region.

During these epochs the sea abounded in swimming reptiles, some of gigantic size, whose remains have been found at several points; also sharks and a great variety of other fish, although the remains of these are not abundant at most points.

After the Cretaceous period the sea seems to have receded rapidly toward the northwest, and all eastern Dakota again became dry land.

During the early Tertiary, according to the prevalent view, large rivers deposited widespread sediments in the region to the west and southwest, but this area received little material and probably abounded in vegetation and animal life which exhibited features not markedly different from those of the present age. Probably the climate was then much warmer and moister. During the later part of the Tertiary there was doubtless a large stream somewhere near the present position of James River, flowing southward. Into this White River probably came, through the basin of White Lake and the valley of Firesteel Creek. These rivers doubtless had many small tributaries, which rapidly cut into the soft material composing the surface. The elevated region in the southwestern part of Davidson County may be considered as a remnant of the old divide south of White River. This older James River seems to have made for itself a large valley, which was much wider than the valley of Missouri River. Apparently it did not cut down to the depth of the present James River.

During the Pleistocene epoch the great ice sheet moved down James River Valley, entering it probably from the north and northeast. It advanced slowly, preceded by waters from the melting ice, which gradually spread a mantle of sand and gravel over nearly the whole pre-Glacial surface. This ice sheet flowed according to the slope of the pre-Glacial surface, moving more rapidly on the lower and more open portions of the valley, and becoming almost stranded on the higher elevations. It certainly extended as far as the outer, or Altamont, moraine. Some geologists are confident that it extended down the Missouri Valley and became confluent with the similar sheet flowing down the Minnesota and Des Moines valleys, both sheets extending into Kansas and central Missouri. However that may be, during the formation of the Altamont moraine the ice filled the whole James River Valley and extended westward at different points to the present channel of Missouri River, near Andes Lake, Bonhomme, and Gayville, so that the

Altamont moraine forms an almost continuous ridge or system of stony hills around the edge of the ice sheet of that epoch, except where it was removed or rearranged by escaping waters. Morainal deposits of this stage are not found in this quadrangle.

In course of time the strength of the ice current was checked and the front gradually melted back, until perhaps a portion of this quadrangle was uncovered. It is barely possible that the marsh deposits near the southwest corner of the quadrangle, before referred to as possibly of pre-Glacial age, are to be referred to that time, but as no till is known to occur under them, and so far as known they rest on Cretaceous clays, they seem to antedate the coming of the ice.

After this period of retreat the ice sheet readvanced and formed the first member of the Gary moraine. At that time the northeast corner of this area was uncovered, and the drainage from the east side of the ice passed down the valley east of De Smet into the Big Sioux.

While the third or Antelope moraine was being formed the drainage was largely down Redstone Creek, which discharged into a shallow basin in the vicinity of Forestburg, probably occupied much of the time by water. A small portion of this area extended into the southwest corner of this quadrangle. The last appearance of the ice in this quadrangle was as an almost stagnant glacier occupying several square miles in the northwest corner.

After the retreat of the ice the streams occupied their present courses, and though at first they were somewhat larger than they now are, they have affected the surface of the country little except to deepen the channels which were occupied by permanent water. It is believed that James River had cut nearly to its present depth before the ice disappeared. The main change since the disappearance of the ice has been the formation of soil, by the accumulation of alluvium along the principal streams, by the deepening of fine material over the general surface through the burrowing of animals, by the wash from the hillsides, and by the settling of dust from the atmosphere.

ECONOMIC GEOLOGY.

This quadrangle contains no deposits of valuable metals or of coal. The few samples which are sometimes submitted as "mineral" are invariably iron pyrites, which has no value unless found in very large quantities. Fragments of coal are sometimes found in the drift, in either gravel or till, but they have been brought by the ice or by streams from the northern part of the James River Valley, in which are found beds of lignite—the so-called coal of North Dakota.

BUILDING STONE.

The most abundant stone in the quadrangle is that brought by the Pleistocene glaciers. It is in the form of bowlders, which are scattered over most of the country, but are much more abundant in the morainic areas. These bowlders consist mainly of granite and limestone. They are not easily prepared for ordinary building purposes, because of their hardness and toughness, and thus far they have been used principally for foundations.

CLAY.

Although the till is composed largely of clay, it is so mixed with gravel, and especially with calcareous matter, that it has nowhere been successfully used for economic purposes, not even in the manufacture of brick. Deposits of clay of economic value are not common. Diligent search might disclose beds of silt in the larger valleys, or of gumbo in the lake basins, in sufficient quantity to be of some local value in making brick, but there is apt to be so much lime and coarse material mingled with them that probably bricks will not be manufactured extensively. Near De Smet two companies have been manufacturing common building brick for some years.

SAND AND GRAVEL.

Plastering sand and gravel suitable for ordinary purposes are found at many points, especially along the ancient channels and terraces and in some of the knolls in the morainic areas.

WATER RESOURCES.

Under this head is included an account of the most important natural resource of this quadrangle, water, which may be divided into surface waters and subterranean waters. Under surface waters are included lakes, springs, and streams, and under subterranean waters the sources which furnish shallow wells, artesian wells, and tubular or deep pump wells.

Surface Waters.

Lakes.—Lakes receive their waters directly from the rainfall, and endure according to the extent of the drainage basins, their depth, and the amount of rainfall, which varies greatly in different seasons, but it averages about 20 inches a year. After a succession of wet years the lake beds over the whole district are full of water, and are usually filled in the spring, if there has been much snow during the winter. In the latter part of summer most of the ponds become dry. Within the last twenty-five years some of these lakes have remained throughout a summer with 10 or 15 feet of water, while a few years later they were dry enough for tillage. One of the largest and most notable is Spirit Lake, about 6 miles north of De Smet. It is a broad unfilled portion of the channel east of the Gary moraine.

Streams.—There are no streams in this quadrangle which furnish water the year round. After a rain or when the snow melts, the watercourses are sometimes so filled with water as to be impassable, but at most seasons of the year they show only a series of ponds scattered along their channels. These retain a small portion of the rainfall. In these valleys underground water circulates sufficiently to prevent the stagnation of the ponds. If they are kept free from contamination they afford good water for some time.

Springs.—Permanent springs are rare, though a few occur. They have their source either in the sands and gravel of the older terraces or in sand beds buried in the till. Springs deriving their supply from such sources are usually transient and unreliable. Springs fed from deeper sources are unknown in this quadrangle.

Subterranean Waters.

Waters obtained from below the surface by artificial means will be considered under the headings "Shallow wells," "Tubular wells," and "Artesian wells."

SHALLOW WELLS.

Shallow wells are those supplied by water which has recently fallen on the surface and which can be reached without penetrating an impervious layer. The most common source of supply for these wells is the water that lies near the surface and seeps through the upper portion of the till toward a watercourse wherever there are shallow accumulations of sand that form conduits for it. The water flows slowly through the lower portion of these sand accumulations and appears at intervals in water holes along the upper courses of the more prominent streams.

Shallow wells are common in this quadrangle, and usually obtain water at a depth of from 10 to 30 feet. They do not afford a copious or permanent supply except when located near the bottom of a large depression or near a channel draining a considerable area. The reason for this is that the water comes from the rainfall only, and the region is often subject to continued drought. Only those which are so situated as to draw from a large catchment basin can be counted upon as permanent. If water is not obtained before striking the blue bowlder clay, it will rarely be found until the bottom of the till is reached.

Extensive areas where shallow wells are permanent may be found along the larger channels and basins. This is particularly true of the valley east of De Smet and of larger valleys draining the west slope of the high land in the eastern part of the quadrangle.

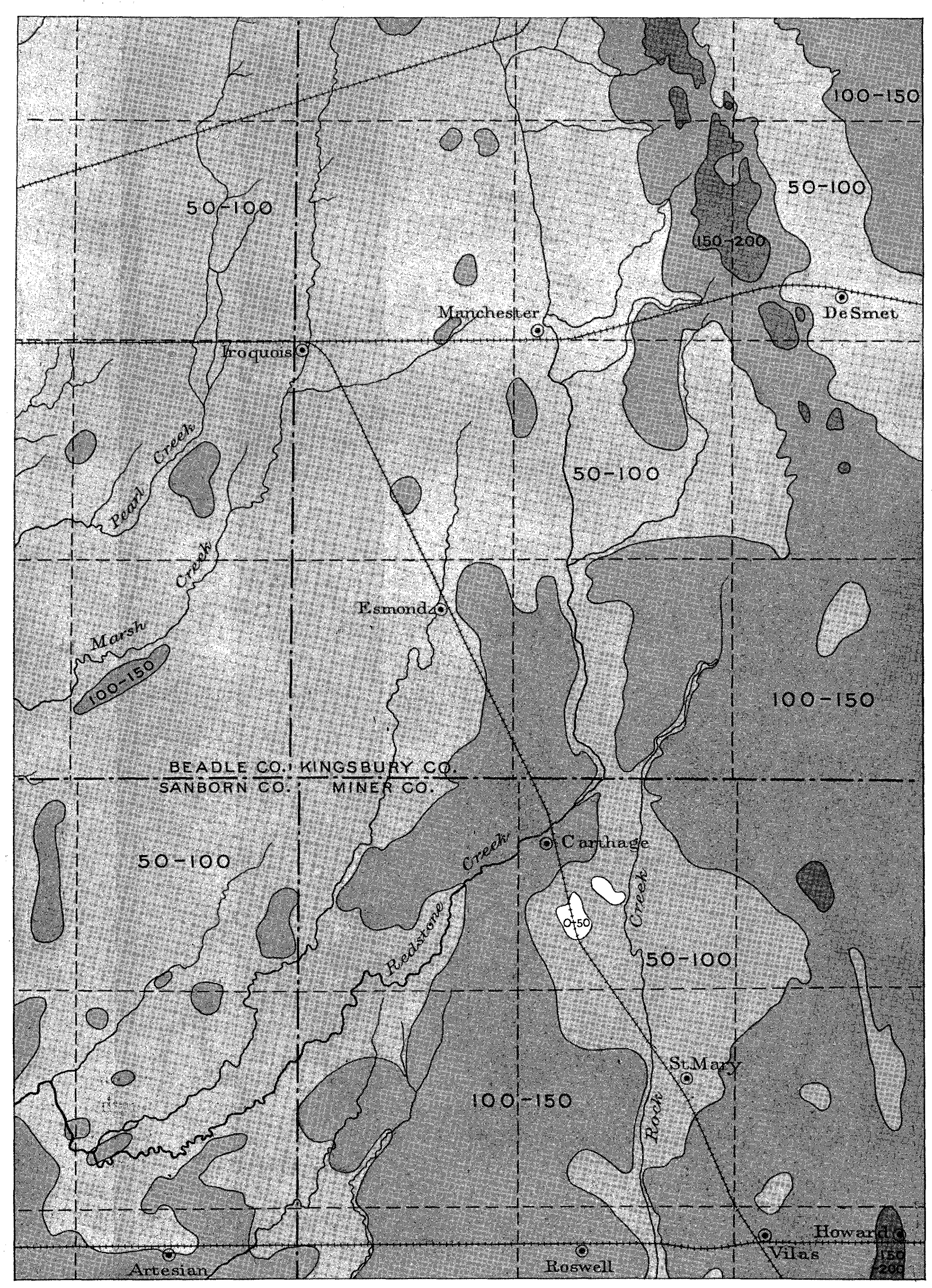

FIG. 7.—Sketch map of De Smet quadrangle showing approximate depths to the bottom of the till. Water can usually be obtained from sands and gravel at the base of the till, and generally rises many feet in wells.

TUBULAR WELLS.

Under this head will be included simply the deeper wells, in which a tubular or force pump is usually necessary, or where the water is only reached after passing through an impervious layer. Such wells are abundant in this quadrangle, particularly in the northern part. They derive water from the sand and gravel at the base of the drift, from a stratum in the Pierre clay above the chalk, and finally from the Benton sandstone below the chalk.

Water from the base of the bowlder clay.—Below the till there is usually a stratum of sand or gravel which commonly is filled with water. The depth to this horizon is shown in fig. 7. At moderate altitudes, as soon as the till has been drilled through, the water rises several feet, sometimes nearly to the surface, but it is heavily charged with lime, and sometimes with iron, and therefore is not desirable, although it is commonly cool and wholesome. At some places the water is so impregnated with other soluble salts from the bowlder clay that it is offensive and even injurious. Perhaps a more frequent difficulty in the way of using this water is the fineness of the sand in which it occurs. It is almost impossible to separate it from the water. This not only makes the water disagreeably roily, but causes the rapid wearing out of the pump. In a few localities of limited area there is no water-bearing sand at the base of the drift, and probably at these places the original surface of Cretaceous clay was so elevated that it was not submerged by the waters attending the advance of the ice sheet, and the till was deposited directly on the Cretaceous clay. Since more desirable water is obtainable in strata a little lower down, this condition is of no great disadvantage.

On the other hand, there are certain areas in which the water in this horizon is under such pressure that it flows at the surface. Such an area extends from the southeast into the southern part of Floyd Township (T. 108 N., R. 60 W.) This will be more fully discussed under the heading "Artesian wells."

Water in the Pierre clay.—The next lower water horizon, that in the Pierre clay, appears to be connected with one found at Huron and Cavour in the area to the west. Apparently it is not at a uniform level, but is struck at depths of from 115 to 175 feet, the depth increasing somewhat toward the north. Since sand has not been distinctly recognized the water may possibly be in local lenses of a porous chalk deposited in the clay. The water from this source is commonly spoken of as being from the "soapstone" and is soft. The 206-foot and 280-foot wells near and north of Miner are probably fed from this horizon.

Water in the Benton sandstone.—The third and most important pump-well horizon is the upper sandstone of the Benton formation, which throughout the quadrangle seems to lie just below the chalk. It is the source of the most desirable and most permanent wells in the whole southern half of the quadrangle, and is well known in the western half. In the eastern half it has not been developed. This is probably due, not to its absence, but to its greater depth and the better supply of water from more accessible strata.

Since this horizon is an unfailing source of soft water, which usually rises within a few feet of the surface, it seems worth while to give in considerable detail the depths at which it may be struck. Beginning at the northwest corner of the quadrangle, it lies at a depth of 350 to 380 feet. In southeastern Beadle County it is reached between 200 and 280 feet. Farther east the depth increases as the surface rises, so that south of Edmond this horizon lies about 420 feet below the surface. Near the southwest corner of the quadrangle its depth is about 150 feet; north of Miner, in T. 107 N., R. 58 W., it is from 280 to 400 feet; near the southeast corner of the quadrangle it seems to be about 440 feet; near Carthage it is 420 feet.

Some of the cases where the water is reached at less depth than usual may be due to its escape from the sandstone into the overlying chalkstone by way of crevices or more porous strata. In this way we may probably account for the remarkable statement that soft water is found in chalkstone;

if this is not the true explanation, the soda salts originally derived from the sea have not yet been washed out and prevent the solution of calcium carbonate.

Another horizon is found lower in the Benton formation which furnishes flowing wells in the western half of the quadrangle. The water has sufficient pressure to rise to nearly 1500 feet above the sea. This horizon affords a pump-well supply in the highlands of the eastern half of the quadrangle. While the supply is not copious enough for satisfactory flowing wells, it may nevertheless furnish water sufficient for an ordinary pump well. At Iroquois this horizon was reached at a depth of about 500 feet; in the southwest corner of T. 109 N., R. 58 W., at the depth of 600 feet; near Manchester at 580 feet, and 3 or 4 miles south of Carthage at 580 feet, although the water at Carthage may be from a lower horizon.

In the southwest corner of the quadrangle the water from this source rises nearly 1300 feet above the sea. Some of the wells in the lower portion of the plain west of Artesian flow rather freely. A short distance farther west, in the town of Forestburg, some of the oldest flowing wells of the region are from this source. If the interpretation given here is correct the water near the eastern side may reach nearly 1400 feet above tide, but this may be due to reinforcement of pressure from water strata lower down.

ARTESIAN WELLS.

In drilling wells, a water-bearing stratum in which the water is under pressure is generally spoken of as a "flow" and the well is classed as "artesian," although some persons would limit the term artesian to wells in which there is sufficient pressure to raise the water to the surface. The latter is the usage employed in this folio. Artesian wells are common in the Huron quadrangle and derive their supply mainly from the Dakota sandstone. Some wells, however, draw their supply from Quaternary sands.

QUATERNARY ARTESIAN WELLS

The Quaternary artesian wells derive their waters from the sand underlying the till. Many wells of this class are found in a strip about 4 miles wide beginning in the southern part of Floyd Township (T. 108 N., R. 60 W.) and the northern part of Oneida, and extending southeast past Artesian to the southern boundary of the quadrangle. They vary in depth from 75 to 100 feet. Their flow is copious but their pressure is slight. As scores of wells have been sunk to this horizon the head has gradually declined. It seems to have fallen 8 to 10 feet in a dozen years. Some wells have ceased to flow and others have been made to continue their flow only by lowering their outlets. These flowing shallow wells are confined to the southwest corner of the area and are rarely over 100 feet in depth. The water usually has a temperature of 50° F. and is hard.

MAIN ARTESIAN SUPPLY.

The main supply of artesian water in this region is undoubtedly derived from the sandstone and sand beds of the Dakota formation, and subordinate flows are found in the Benton. The Dakota formation is the source of artesian water not only under much of eastern South Dakota, but in a wide area in adjoining States. It owes its efficiency to four factors: (1) Its great extent, underlying most of the Great Plains from the Rocky Mountains eastward to about the ninety-fifth meridian; (2) its highly elevated western border, located in the moist region of the mountains and crossed by numerous mountain streams; (3) its being extensively sealed in its eastern margin by the overlapping clays of the Benton formation, and where they are absent by the till sheet of the Glacial epoch; and (4) the cutting of wide valleys, especially in Dakota, by pre-Glacial streams, so as to bring the land surface below the pressure height or "head" generated by the elevated western border of the formation. From this formation is derived a copious pumping supply over wide areas where the pressure is not sufficient to produce flowing wells. The Dakota sandstone underlies the whole quadrangle and rests on the "bed rock" of well drillers. This surface is the limit of profitable boring, depths to which are shown in fig. 8.

The water-bearing strata seem to lie more nearly horizontal and to have a more regular structure in this area than farther south. There are no marked irregularities to indicate local subdivisions of the water-bearing strata, as elsewhere. On the other hand, it is impossible to speak as definitely concerning the depth of the different formations in this quadrangle as in some others, because artesian wells are not so numerous.

Water horizons.—There are four distinct water-bearing strata under the greater part of this area, and in the north-central portion there is probably a fifth. These are known as the first, second, third, and fourth flows, and correspond respectively to the first, second, third, and fourth sandy strata of the Benton and Dakota formations. They seem to be distinct from one another, though observations upon the pressure of the water from each horizon are not yet complete enough to make this point certain. Wells tapping the first flow are those already spoken of as furnishing soft water west of Artesian. The second flow yields soft water, and the quantity is usually so small that it is not generally drawn upon for a permanent supply. A few wells which obtain water from this stratum have flowed for several years, and observations on pressure made farther south, about Letcher, indicate that the flow is unfailing. The water probably comes from a thin stratum of sand which may not be as continuous as the thicker ones below. At several localities it either has not been struck or has been overlooked. This flow is not shown on the artesian water map. At Iroquois the altitude above sea level of this flow is 800 feet, depth 600 feet; in the northeast quarter of sec. 30, T. 109 N., R. 56 W., the altitude is 780 feet, depth also 600 feet.

The next horizon, or third flow, is that which is most frequently drawn upon. The supply is copious and the water although hard is palatable. This flow is struck at an altitude of about 650 feet in the southern part of the quadrangle, 550 feet near Iroquois (depth 850 feet), and at increasing depths as the surface rises to the east.

The positions of the fourth and fifth flows are inferred from the records of the wells near Huron. The fourth was probably struck at De Smet, but the record is not clear enough to make this certain. The depth of the wells from the Dakota is rarely less than 700 feet, and toward the eastern margin is over 900 feet because of the greater elevation of the land.

The wells usually penetrate only bowlder clay, shales, sands, and soft sandstones. The water from them is usually soft in the upper layers, and in the lower is softer toward the north. It has a temperature of 62° to 70° F. Wells 2 inches in diameter furnish from 30 to 100 gallons a minute, according to the porosity of the water rock and the amount of pressure, the latter being the more important condition. Pressures as high as 71 pounds per square inch have been obtained at Iroquois and northwest from there.

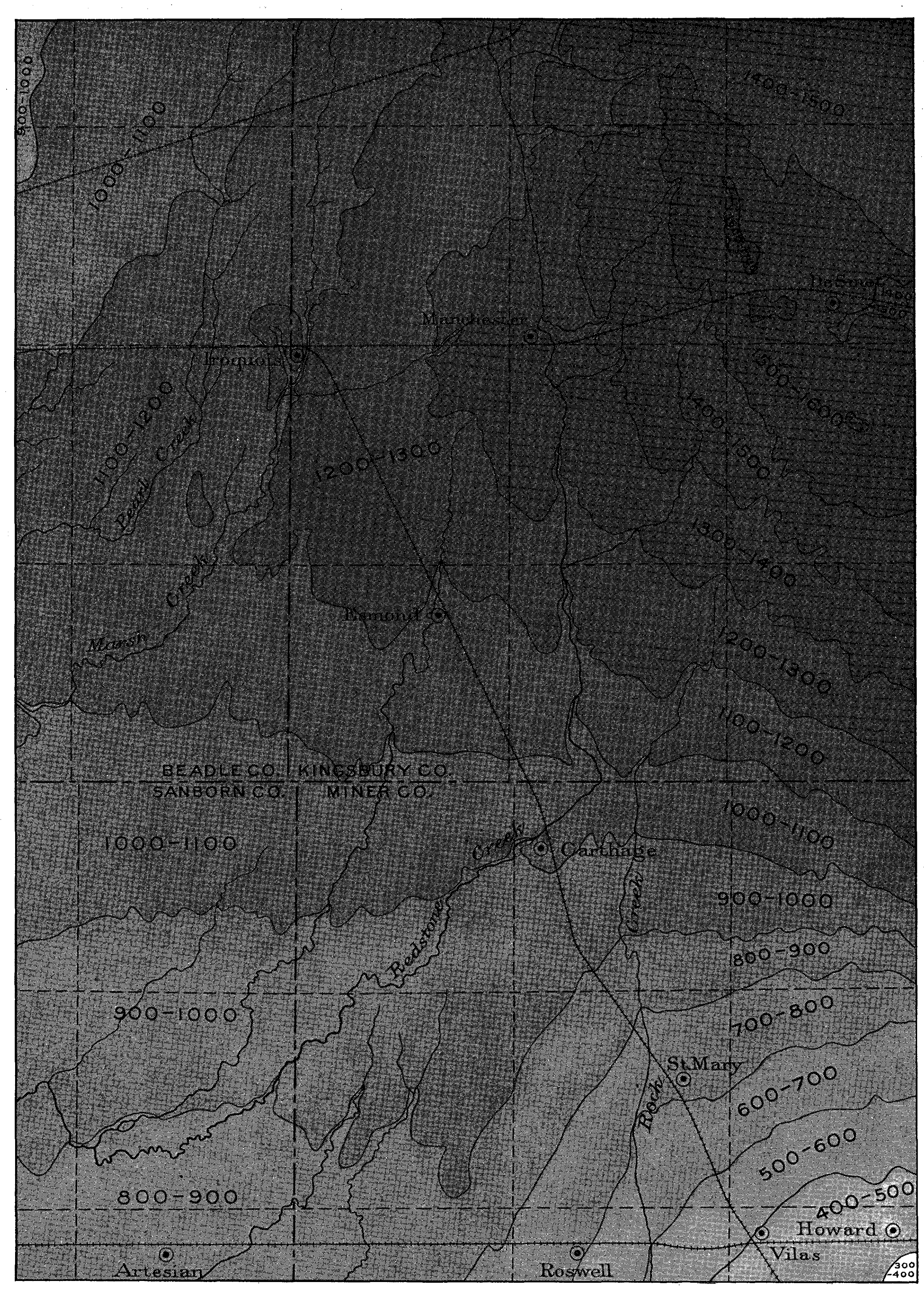

FIG. 8.—Sketch map of De Smet quadrangle showing approximate depths to the surface of the Sioux quartzite, "bed rock" of well drillers, which is the lower limit of water-bearing strata.

Limits of the artesian area.—The limit of the artesian area as drawn on the artesian well map is estimated from the closed pressure observed in the nearest wells, and is therefore more or less approximate. Moreover, the pressure mapped by contours and used in making the estimate is that of the first main flow or the third water stratum below the chalk. It is probable that from lower strata which very possibly underlie the southeast quarter of the quadrangle a somewhat higher pressure may be obtained. If so, the limit will be correspondingly shifted toward the east. It is not probable, however, that the area will be much increased from this cause. The pressure of the Risdon well was 165 pounds when the city well of Huron was 120. That difference would be equivalent to an altitude of 104 feet, but the difference of pressure would doubtless be much less near the margin.

It should be remembered that the limit of the artesian area in this quadrangle is based on lack of pressure, not the absence of the water-bearing strata. Deep pump wells may draw from the artesian supply throughout the whole quadrangle.

Artesian pressure.—From a superficial study of artesian wells some persons think that all the artesian water in a basin has the same head or rises to the same plane. This, however, is far from true, particularly in North Dakota and South Dakota. In general the pressure declines toward the margin of the water-bearing strata. This fact is readily explained in broad basins by supposing that the water is moving as a slow current toward outlets or leaks along the margin of the formation, where the latter laps against the older rocks or where fissures may connect it with the bottoms of streams. Each flow, in general, shows this same decline in pressure toward the southeast.

The lower flows of the Dakota formation have a higher pressure than the upper flows because the leakage into the Sioux quartzite is not so free as into the overlying Benton shale. On the artesian water map are contours representing the altitude of "head," which, in its downward slope southeast, may be regarded as a "hydraulic gradient." It would be impossible to represent the pressure for each water-bearing stratum; therefore the data from the more important wells have been taken; or, in other words, the contours showing altitude of head represent the relative pressure in the more available and accessible stratum. It is not unlikely that in many cases wells sunk to lower flows may have considerably greater pressure.

For several reasons the pressure at the wells in this quadrangle has not been satisfactorily determined. The pressure of the first wells opened was usually much higher than it is at present. The pressure of the lower flows has not been obtained, except possibly in the Risdon well near Huron.

It seems certain that where wells are multiplied in close proximity the pressure steadily declines; that presssures as high as those first reported can not be repeated without closing all the wells at the same time, and that even then days and possibly weeks will have to pass before the water can accumulate sufficiently to replace the local exhaustion.

Making allowance for the local exhaustion, we may conclude that in the latitude of Huron the head increases toward the west at the rate of about 4 feet to the mile. This conclusion is arrived at by comparing the earliest reported pressures. Toward the south the head decreases.

In wells tapping the Dakota formation the water does not rise higher than an altitude of about 1650 feet in the vicinity of Iroquois, and the pressure declines toward the east at such a rate that a plane corresponding to the declension would cut the east slope of the valley at an altitude, near the north border of the quadrangle, of about 1640 feet. The contour line representing this level may be considered as the eastern boundary of the artesian area as far south as the southern line of Manchester Township (T. 110 N., R. 57 W.). As the pressure decreases somewhat toward the south the boundary of the artesian area would be at a less altitude because of the insufficient pressure, but as the lower flows or water-bearing strata have not been proved to be present toward the southern part of the quadrangle and the pressure is less in the higher flows, the eastern boundary is deflected to the west, as is indicated on the map.

A deep boring at De Smet is said to have developed a pressure sufficient to raise water within 40 feet of the top of the well, or 1730 feet above the sea. This statement is irreconcilable with facts known from the area farther west. If the facts were really as reported it seems more probable that the water in the well was due to local leakage from outside, although this explanation can not be considered satisfactory.

In this quadrangle there appears to be, in some flows at least, a diminution in pressure toward the west. At first glance this appears anomalous, but the apparent anomaly may be explained by assuming an extension of this local exhaustion so as to affect the area farther west. Several large wells in the James River Valley supplied from this source have been flowing for some time, and they may well have locally relieved the pressure. Since in the high lands away from large streams the leakage from the different water-bearing strata is much less than in the James River Valley, the water which was stored in the strata before the opening of the numerous wells of the James River Valley may still afford a pressure corresponding to that in the wells first opened there. If this conclusion is correct, a more rapid decline near the margin of the artesian area than would otherwise occur may be expected.

Causes of apparent decline in pressure.—It is now generally admitted not only that the amount of water flowing from each well rapidly decreases, but that the closed pressure also declines. This becomes evident without the use of instruments, first by a shortening of the distance to which the water is thrown from a horizontal pipe, and second by the fact that after a time the stream which first filled a given pipe fails to do so. In some cases a test with the gage shows that this is merely a decline in amount of flow without material decline in pressure. It may be accounted for by the deposition of mineral matter about the bottom of the pipe in such a way as to clog the pores of the sand through which the water comes. In the wells at Huron, some that once showed a pressure of 120 pounds when closed now fail to reach 80. Similar facts have been reported from Mitchell, Mount Vernon, and Plankinton.

The unwelcome conclusion derived from these facts has led many persons to search for other reasons than the one first suggested, the partial exhaustion of the artesian supply. It is claimed, and apparently correctly, that new wells frequently have a pressure equal to that of early wells supplied from the same source. Since the closed pressures, however, are less frequently taken than formerly, and from the nature of the case liberal allowance must usually be made for leakage, it is difficult to prove the strict truth of this statement.

The first sign of apparent decline is a less copious flow. This is usually due to the clogging of the well. As wells are usually finished by extending a perforated pipe into the water-bearing rock, it will be readily seen that the surface opened for the delivery of water to the well is equal to the perforated portion of the pipe. As the water continues to flow, sand gradually accumulates on the inside of the pipe and so diminishes the surface supplying water to the well. Something of the same sort may less frequently occur even when the pipe terminates in the cap rock. Sand gradually works in from the sides, and portions of the cap rock are undermined and drop down, so that free access of the water is considerably diminished.

Theoretically the closed pressure should be the same whether the well is flowing freely or not, so long as the head of the water is the same. If the well becomes clogged, as suggested above, the only difference in pressure will be that when a gage is attached it will take longer to reach the maximum point. As this rise may be very gradual, some errors of reading have doubtless resulted because the observers did not wait long enough.

Another cause of diminished pressure is leakage. As is well known, pipes deteriorate rapidly under the influence of most artesian water, and it becomes almost impossible to close the joints perfectly. Where there is a long pipe, as in the case of the distributing pipes of a city, one can never be sure that all leaks are stopped. This may sometimes explain the apparently diminished pressure in older wells.

The diminished pressure in a particular well may sometimes be due to the opening of another well not far away. The distance to which this influence extends will of course be greater where the water-bearing stratum is of coarse texture and the movement of the water freer. Where water has been drawn freely from several wells, or even from one large well, there is no doubt a local depression in the head, or lowering of pressure, which may not be restored for some time. This might occur without permanent decline of supply.

Notwithstanding all the considerations offered thus far, it seems not unlikely that the rapid multiplication of wells in any region may really reduce the pressure over the whole region to the amount of a few pounds. It is therefore important that facts should be collected to ascertain whether this is the case, and if so, to determine the amount of diminution. In view of the possibility of overtaxing the supply, it would seem desirable to limit in some way the number of large wells allowed to flow freely. A single thousand-gallon-a-minute well would be sufficient to supply 450 wells furnishing 100 barrels a day, which would be adequate for an ordinary farm.

The closing of wells.—Much damage is sometimes done by the free running of wells. In some cases large wells have been drilled for irrigation purposes and, sufficient rainfall for a series of years rendering them unnecessary, the water has been allowed to run to waste, thereby drawing unnecessarily upon the general supply. Moreover, it has often rendered considerable land in the vicinity unproductive. The practice, therefore, of closing wells when not needed is recommended. The only objection to this is the fear which some have that wells when closed will become clogged. This danger may be avoided by a gradual closing of a well, even when it is known to carry some sediment. When the water runs clear, and especially where the well has never thrown sand, there is very little danger. Some large wells made to furnish power are habitually kept closed when not in use, without serious injury. In case a well should become clogged by the settling of sand, it may often be opened by letting down an iron rod and churning it up and down until the flow is started. To avoid too sudden changes in the flow, which may produce injurious effects at the bottom of the well, the opening and closing should be done gradually.

SOILS.

The soils of this quadrangle have not been carefully studied, and only the more obvious characteristics are noted below. They may be divided into stony soils, sandy soils, clayey soils.

Stony soils are found only in limited areas mainly upon the rougher surface of the moraines and along the edges of the deeper ravines. The bowlders usually lie almost entirely upon the surface, so that they are easily removed. Sandy areas such as occur near James River are unknown in this quadrangle. The few limited areas in which they are found are due to the separation of the sand from the till by local wash, and are not important. Under loamy soils are included the soils usually covering the surface of the till and most areas of alluvium. The action of frost, the bleaching influence of surface waters, the mingling of dust from the atmosphere, and the work of burrowing animals have all contributed to produce this kind of soil from the bowlder clay. Such soil is fertile and generally of sufficient depth except upon the highest points of the till.

The alluvial areas in this quadrangle are small because of the rarity of flood plains, either recent or ancient. The most extensive areas are around the lakes in the northeast corner of the quadrangle. Clayey soils, presenting the usual "gumbo" characteristics of being very soft and sticky when wet and intensely hard when dry, are found only in limited areas scattered more or less over the whole quadrangle, in the bottoms of the larger lake basins. Where the basins are small, ordinary cultivation mingles these soils with the surrounding loamy soil, to the advantage of both.

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